LOCA DUCTILITY TESTS

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Safety analyses for loss-of-coolant-accidents (LOCA) address several phenomena related to the behavior of fuel rod cladding: (a) ballooning deformation, (b) conditions for bursting, (c) oxidation kinetics, and (d) embrittlement. The first three are described by correlations, and cladding embrittlement is addressed by criteria in 10 CFR 50.46. These embrittlement criteria currently consist of a 17% limit on cladding oxidation and a 2200°F (1204°C) limit on cladding temperature.

A program of LOCA testing is being performed at Argonne National Laboratory (ANL) for the NRC in cooperation with the Electric Power Research Institute, Framatome ANP, and the Department of Energy. The original motivation for the LOCA testing at ANL was to look for burnup effects on the embrittlement criteria, with burnup effects on ballooning, bursting, and oxidation as secondary interests. More recently, proposals have been made to replace the Zircaloy-based 17% and 2200°F limits with a performance based requirement in 10 CFR 50.46 to avoid the need for regulatory exemptions when new alloys are introduced and to accommodate any burnup effects. These current numerical limits were derived from ductility tests, so the proposal included the substitution of some suitable ductility test [1,2].

After considering several possibilities, it has been decided to continue investigating the ring-compression test as the potential performance-based ductility test for 10 CFR 50.46, provided that it can be confirmed to be adequate. Ring-compression tests are less expensive to perform than the alternatives, and because such tests were used to develop the original embrittlement criteria, their continued use should contribute to regulatory stability. Two basic questions of adequacy will be addressed in the current research program. One is about our ability to interpret the results of ring-compression tests unambiguously, and the other is about the efficacy of a test on a small ring specimen to represent the behavior of a fuel rod in a ballooned and ruptured region.

Although more costly, a three-point bend test is probably better in several respects than a ring-compression test. The first advantage of this test is that the tensile loads are applied in the axial direction rather than in the circumferential direction. This is probably more representative of stresses that might arise from horizontal accelerations (earthquakes), plant vibrations, and spacer grid interactions. Furthermore, the load-vs-deflection curve for this test is simple and easy to interpret. If the ring-compression test and the three-point bend test both show the same critical cladding oxidation level for the same material, then we can use the less expensive ring-compression test.

Four-point bend tests on segments containing a ballooned and burst region will also be performed in the ANL program. This test, with fuel pellets inside, is most prototypical for investigating the behavior of the ballooned region of a fuel rod. Double-sided oxidation will take place as appropriate, with steam entering through the burst opening. Any enhanced hydride absorption due to inside oxidation will be present. Loading points are away from the deformed region, and the specimen will break naturally at its weakest location. While this is clearly the most expensive test, it only needs to be used in a confirmatory way. If results from the ring-compression tests can be applied in the ballooned region, and if those results adequately predicts ductile or brittle behavior, then the ring-compression tests will have been confirmed.

The ring-compression tests, hopefully confirmed by three-point bend tests, and the four-point bend tests will be integrated into the overall LOCA test program. Unirradiated tubing, as received, will be tested first. Irradiated cladding, as it becomes available, and hydrogen-charged tubing will be tested later to investigate burnup effects. Two or more alloys will be oxidized together in the same furnace to reduce the number of furnace runs needed to produce ring specimens (and three-point bend specimens, if necessary). Oxidation kinetics can also be obtained from these furnace runs, and examination of ring fragments after compression will give fracture morphology and oxygen content. Specimens for the four-point bend tests will consist of those specimens that survive thermal shock in integral tests. After optical profilometry, those specimens will be tested in the four-point bend apparatus and will likely break. Metallography and hydrogen measurements can be made on fragments after the bend tests. Schematic diagrams of the test procedures and the test matrix have been developed and will be described in the paper.

References

1. SECY-01-0133, “Status Report on Study of Risk-Informed Changes to the Technical Requirements of 10CFR Part 50 (Option 3) and Recommendations on Risk-Informed Changes to 10 CFR 50.46 ECCS Acceptance Criteria, July 23, 2001.

2. Ashok C. Thadani, “Research Information Letter 0202, Revision of 10 CFR 50.46 and Appendix K,” NRC memorandum to Samuel J. Collins (ADAMS #ML021720744), June 20, 2002.